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ON TIDAL PERIODICITY

IN THE

EARTHQUAKES OF ASSAM.

BY

R. D. OLDHAM.

Extract from the Journal of the Asiatic Society of Bengal,
Vol. LXXI, pp. 139-153, 1902.

CALCUTTA:
BAPTIST MISSION PRESS.
1902.

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From the Journal, Asiatic Society of Bengal, Vol. LXXI, Part II, No. 3.
1902.

On Tidal Periodicity in the Earthquakes of Assam.—*By* R. D. OLDHAM, *Superintendent, Geological Survey of India.*

(Communicated by permission of the Director of the Geological Survey of India). [Received July 21st, Read August 6th, 1902.]

I.—INTRODUCTORY.

Ever since earthquakes were first studied there have been repeated and persistent attempts to trace the action of the sun, the moon, and the planets in producing them, or at the least in influencing their relative frequency. Mallet, from the discussion of his great earthquake catalogue [1], found that there was a marked periodicity, which caused earthquakes to have a maximum frequency towards the end of each century, with a minor, but nearly as great, maximum a little before the middle; and, more recently, Dr. A. Cancani has remarked a similar peculiarity in the earthquakes of Italy.[2] Periods of this length, however, have no direct and obvious connection with the movements of the heavenly bodies, and more interest attaches to variations of shorter periods. Perrey, and following him Mallet,[3] believed that they had detected such variations, and that the frequency of earthquakes showed a relation to the distance of the sun and the moon from the earth, and to their relative positions in the heavens, at the syzygies and quadratures. As a result of this careful investigation it had been generally accepted that earthquakes were more frequent during winter than in summer and during the night than during the day.

In 1889 the subject was again attacked by M. F. deMontessus de Ballore,[4] who started by preparing a catalogue of 45,000 earthquakes. From this he proceeded to discuss the diurnal periodicity, and found that though each individual list and record showed a distinct periodicity, there was no agreement among them and that the larger the number of shocks taken the more uniform became the resulting distribution of earthquakes throughout the day and night. In a subsequent paper[5] he applied the same treatment to the seasonal periodicity with a similar result and came to the conclusion that there was no real variation in the frequency of earthquakes, which he regarded as a purely geological phenomenon, unaffected by either astronomical or meteorological influences.

About the same time Dr. Davison began his investigation of earthquake frequency, and in a laborious paper,[1] on the annual and semi-annual periodicity of earthquakes, came to the conclusion that, treating each region separately, there was a distinct variation in frequency, which was in excess of that which might be expected if the occurrence of earthquakes was in no way connected with the seasons.

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[1] Rep. Brit. Ass., xxviiii, (1858).

[2] Boll. Soc. Sismol. Ital vii, 205-209 (1901).

[3] Brit. Ass. Rep., xxviii, (1858).

[4] Archives des Sciences Physiques et Naturelles, 3. Ser., xxii, 409, (1889).

[5] Archives des Sciences Physiques et Naturelles, 3. Ser., xxv, 504, (1891).

From this brief review it will be seen that the question, of whether earthquakes are at all affected by extra-terrestrial influences, is at present an open one, and for this reason I made every effort, after the great earthquake of 1897, to obtain the fullest possible record of the extremely numerous after-shocks, thinking that if there was any external cause at work it should be especially easy to trace at a time when, and in a region where, the earth's crust was evidently in an extremely unstable condition. The discussion of these records is not complete but in the case of one of them it has been completed, so far as one particular phase of the frequency is concerned, and the results obtained appear to be of sufficient interest to justify some notice of them.

In July of 1897, Mr. T. D. LaTouche, who was then in Shillong reporting on the results of the earthquake, constructed a seismograph on the duplex pendulum system, which was set up by the Executive Engineer, and from which continuous records have been taken ever since. The instrument, like all seismographs, is far from a perfect one, it does not record many shocks which can be distinctly felt, and it does not record the time, yet the records are of great value. In the first place we know that every shock recorded attained a certain standard of range of motion of the wave particle and of violence, if such a word may be applied to what in many cases are merely slight shocks, and that all the shocks exceeding this standard are recorded. The absence of automatic time record is more serious, but as the time of the shock was, in every case, recorded by the observer we may take it that there is no very serious error or omission in this respect. Every shock recorded represents one at approximately the time given, and the only cause likely to affect the periodicity is a possible error in the case of the night shocks: it is possible that the instrument may at times have registered a shock while the observer was asleep, and the record afterwards referred to one, felt when he was awake, which did not affect the instrument. The uncertainty due to this cause is, however, slight, as the gentlest shock registered by the instrument is sufficiently strong to usually awake a sleeper.

From this instrument we have received records from August 1897, but those discussed as yet only extend to the end of 1901; so far they have only been examined with a view to the hourly variation in

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[1] Phil. Trans. clxxxiv, A, 1107 (1893).

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frequency, and instead of contenting myself with a mere record of the relative frequency of the earthquakes, as has usually been done in the past, I have made an attempt to see whether there is any trace of extra-terrestrial influence in this frequency.

As pointed out by me in a short note published in 1901[1] any effect which the attraction of the sun and the moon may have, will be most effectively, if not solely, exerted by the Tide-producing forces they set up, and that, to trace the effect of these, it is not sufficient to merely tabulate earthquakes by the hours in which they occur. The time at which the tide-producing forces reach their maximum depends on the declination of the sun and the moon, that is to say it is subject to seasonal variations, and to determine whether these forces have any influence it is necessary to classify the records, according to the position of the sun or moon with reference to the equator, and then examine the frequency to see whether there is any variation which can be correlated with the tidal forces.

II.—STATEMENT OF THE PROBLEM.

There is neither space nor occasion to recapitulate what is known of the theory of the tides, but a brief account of the form of the tide-producing influence of the attraction of the sun and the moon is desirable, that the nature of the effect to be looked for may be clearly understood, and the review will be simplified by the fact that we need not consider the theory of the tides themselves, but merely of the stresses to which they owe their origin. Omitting all reference to the why, it will be sufficient to point out that the effect of the attraction of a satellite—and in this connection the sun is regarded as a satellite equally with the moon—is to produce a stress equivalent to an upward force at the spot which is at any moment directly under the satellite, and at the antipodes of that spot. Along the great circle half way between these two spots, separated from each by 90° of arc, there is a force acting downwards towards the centre of the earth, and equal in amount to one half of the upward force. At spots between these two points and the great circle just referred to, the stresses produced are equivalent to forces acting in directions away from the vertical, and along a circle which is distant about 54° 44′ 14″ from the spots where the satellite is in the zenith or nadir the force acts horizontally.

Now if we suppose the force exerted at any point to be resolved into two separate forces, one acting vertically and the other horizontally, then the vertical force attains its upward maximum where the satellite is in the zenith or nadir, and its downward maximum along the great circle intersecting the line joining these two points and lying at right angles to it. The horizontal force attains its maximum along two circles distant about 54° 44′ from the zenith and nadir respectively, the direction being towards the satellite in the former case and away from it in the latter. If then the tidal stresses have any influence in determining the time of origin of earthquakes we should look for the effect in connection with these circles.

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[1] Geol. Mag. 4. Decade, viii, 449, (1901).

Both sun and moon, as is well known, vary their position in the heavens, travelling alternately north and south of the equator, the sun moving to about 23°, and the moon to about 26°, from it. From this it follows that neither can ever be in the zenith of any spot distant more than 26° from the earth's equator, that is in more than 26° of latitude either north or south, and no spot situated outside those limits can ever experience the maximum upward force. Within those limits, at either one or two periods in each year, when the declination of the sun and the latitude of any given place are the same in amount and sign, the maximum upward force, due to the sun, will be experienced at midday and midnight; and similarly in each lunar month there will be either one or two periods at which the maximum upward force will be experienced, when the moon is either overhead, mid-moon-day, or underfoot, mid-moon-night. Outside the limits of the two 26° parallels, and within them at all times when the declination of the sun or moon is different in amount or sign from the latitude, the maximum upward force will not be experienced, but, as the earth revolves on its axis, the circles of maximum horizontal and downward force sweep over its surface, and pass any given place at an interval, before and after the meridian passage of the satellite, which depends on the declination of the satellite at the time and the latitude of the place.

From these considerations it will be seen that, before discussing the frequency of earthquakes with reference to the tidal stresses, it is necessary to group them according to their place of origin, and then see whether, for any one district, there is a connection between the relative frequency of earthquakes and the times of passage, over the epicentre, of the circles of maximum tidal force.

One method of discovering whether there is any such connection would be to calculate for each earthquake the exact time which separated the time of its origin from that of the passage of each of the circles of maximum tidal force, and then to classify the records according to these intervals, and see whether there was any preponderance of earthquakes at or about these times. The process would be a laborious one, and, in view of the want of exact accuracy in the times, did not seem worth going through, as a result within the limits of accuracy of the records can be obtained in a simpler manner.

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We may assume that the epicentres of the earthquakes now under consideration all lie in 26° N. Lat., without introducing any material error, and, calculating for that latitude the time intervals, which elapse between the meridian passage of the satellite and the passage of the tidal circles, we obtain, for extreme and mean values of declination the intervals given in the tabular statement below, [1] where 0 h represents the lower, and 12 h. the upper, meridian passage, or midnight and midday in the case of the sun.

I.—*Table showing the times of passage of circles of maximum horizontal and vertical Tide-producing force; calculated for Lat. 26° N.*

Decl.	Hor. force, Direct.	Vert. force, Downward.	Hor. force, Indirect.
	12 h. ± h. m.	0 h. ± h. m.	0 h. ± h. m.
26° N.	4-15	4-38	——
9° N.	3-31	5-34	2-14
0°	2-59	6-0	2-59
9° S.	2-14	6-26	3-31
26° S.	——	7-22	4-15

From this table it is obvious that, if the total number of shocks is divided into three groups, according to the position of the sun, the first comprising those which occurred when the sun was more than 9° N., the second when its declination did not exceed 9° N. or S. and the third when the declination was more than 9° S., then in the first group the effect of the horizontal force must be looked for between 3½ and 4 hours before and after midday, and within two hours on each side of midnight; in the second group the effect is to be looked for between 3 and 3½ hours on either side of midnight and midday; while in the third the condition will be the same as in the first, with the substitution of midnight and midday. Moreover, as the effect may be due rather to the rapidity of changes in the amount, than to the actual amount, of the force exerted, the horizontal force may have but small influence when the passage of the circles takes place at less than two hours on either side of the meridian passage, that is to say, when the intersection of the circles is oblique, and the rate and range of change in the amount of force is less than when the passage takes place at a greater time-interval than 2 hours from the meridian passage. This, combined with the much greater length of time during which the interval exceeds three hours, shows that in a general list of all the shocks the effect must be looked for between 3 and 4 hours on either side of midday and midnight. Further, as it is a common phenomenon in nature that the maximum of effect lags behind the maximum of cause, it may be that the effect will not be found between 3 and 4 hours on either side of the meridian passages, but at some time after that epoch. Another effect which may be looked for, which follows from the consideration of the greater efficiency of the force when its rate of variation is greater, is that we may expect the number of shocks recorded during the day to be proportionately greater when the sun is more than 9° N., that is during the summer, and the night shocks to be proportionately more numerous during the winter, when the sun is more than 9° South of the equator.

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[1] The intervals are not exactly the same on either side of the meridian passage on account of the motion of the sun and moon in the heavens, but the inequality is not sufficient to be of importance in this connection.

There is another supposition which must also be tested, that the effect, if any, of the tidal forces is not to be looked for in connection with the times when they attain their maximum, but with the times at which the rate of change, of amount and direction of the forces, is at its maximum. For any particular place the rate of change always reaches its maximum at 3 hours before and after the meridian passage, but along a great circle, passing through the place of observation and the place where the satellite is in the zenith, the maximum rate of change is at 45° from the latter, and it will be useful to see what is the time interval for different declinations at which a circle 45° distant from this spot passes the place of observation. The result is given in the following table.

II.—*Times of passage of circles of maximum rate of change of the Tide-producing forces calculated for Lat.* 26° *N.*

Decl.	Direct.	Indirect.
	12h ±	0 h ±
	h. m.	h. m.
26°N.	3-22	——
9°N.	2-56	1-56
0°	2-33	2-33
9°S.	1-56	2-56
26°S.	——	3-22

It must be distinctly understood that the times given in this table are not those at which the rate of change is actually greatest, but those at which the rate is greatest, as measured along a different circle to the east and west one, along which the place of observation travels. In the solitary case where this place and the satellite are both on the equator the two agree, and in no other; but the table is useful, for the closer the

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value in the table approximates to 3 hours the greater is that rate of change, and the closer it lies to 0 h. or 12 h. the less is the rate of variation of the tide-producing forces.

The passage of the circles of maximum vertical force is not subject to the same changes as that of the other circles, and never varies more than 1 h. 22 m. from six o'clock; the effect of this force must therefore be looked for about that time in the morning and evening or somewhat later.

Finally, it is necessary to notice one objection, which might be raised to the preceding passages, that the effect is not necessarily to be looked for at any fixed time before or after the meridian passage of the satellite, but that, for each place, there will be something equivalent to what is known as the "establishment" of a port in the case of marine tides. The objection, however, is not valid, for in this case we have not to do with free travelling waves, like that of the tides, which take a greater or less time to travel from the place where they originate to the place where they are felt, but with the direct effect of the stresses which produce the waves. These depend solely on the latitude of the place and the declination of the satellite, and for them there is nothing in any way analagous to the " establishment " to be considered.

III. DISCUSSION OF THE DATA.

After this preliminary exposition of what is to be looked for, we may pass on to a consideration of the results obtained. In the record discussed there are contained 1274 distinct shocks, and, on counting these, it was found that, in each hour of the twenty-four, the number of shocks recorded was as given in the tabular statement No. III, where all shocks recorded from 0 h. to 0 h. 59 m. are placed under 0, those between 1 h. and 1 h. 59 m. under 1 and so on.

The most casual inspection of this table shows that the shocks are not at all uniformly distributed during the twenty-four hours, and that there is a great preponderance during the hours preceding midnight, with a lesser increase towards 6 A.M. It may also be noted that the night shocks seem more numerous when the sun is more that 9° S and the day shocks when it is more than 9° N, but no proper comparison is possible on account of the difference in the total number of shocks in each line. For comparison they must be brought all to the same ratio, and this may be done, either by calculating the percentage of the total number of shocks recorded in each hour, or more simply by dividing each figure by the mean value for the line; this gives a result showing the proportion of the number of shocks recorded in each hour to the average number for one hour. In this way we get the result shown in the next tabular statement.

III.—*Hourly distribution of Shocks.*

Sun's Declination. / Hours	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL.
>9°N ...	11	15	16	12	13	24	24	8	22	12	22	21	16	13	22	12	27	16	14	17	21	30	28	20	436
9°N-9°S ...	5	8	14	14	26	14	16	16	9	15	13	14	11	18	9	22	22	11	12	13	19	17	21	19	358
>9°S ...	17	21	29	29	22	19	30	16	10	15	8	19	16	12	17	13	22	19	22	20	20	24	41	19	480
TOTAL ...	33	44	59	55	61	57	70	40	41	42	43	54	43	43	48	47	71	46	48	50	60	71	90	58	1274

IV.—*Proportionate distribution of Shocks by hours.*

Sun's Declination. / Hours	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
> 9°N ...	·61	·83	·88	·66	·71	1·32	1·32	·44	1·21	·66	1·21	1·16	·88	·72	1· 1	·66	1·49	·88	·77	·93	1·16	1·65	1·54	1·10
9°N-9S ...	·33	·54	·94	·94	1·74	·94	1·07	1·07	·60	1·01	·87	·94	·74	1·21	·60	1·47	1·47	·74	·81	·87	1·27	1·14	1·41	1·27
>9°S ...	·85	1·05	1·45	1·45	1·10	·95	1·50	·80	·50	·75	·40	·95	·80	·60	·85	·65	1·10	·95	1·10	1·00	1·00	1·20	2· 5	·95
All shocks ...	·60	·80	1·09	1·02	·19	1·07	1·30	·77	·77	·80	·83	1·02	·80	·84	·89	·93	1·35	·86	·	·94	1·14	1·32	1·67	11·1

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Shillong Seismograph 1897-1901. Hourly curve of frequency smoothed by means of 3 hours.

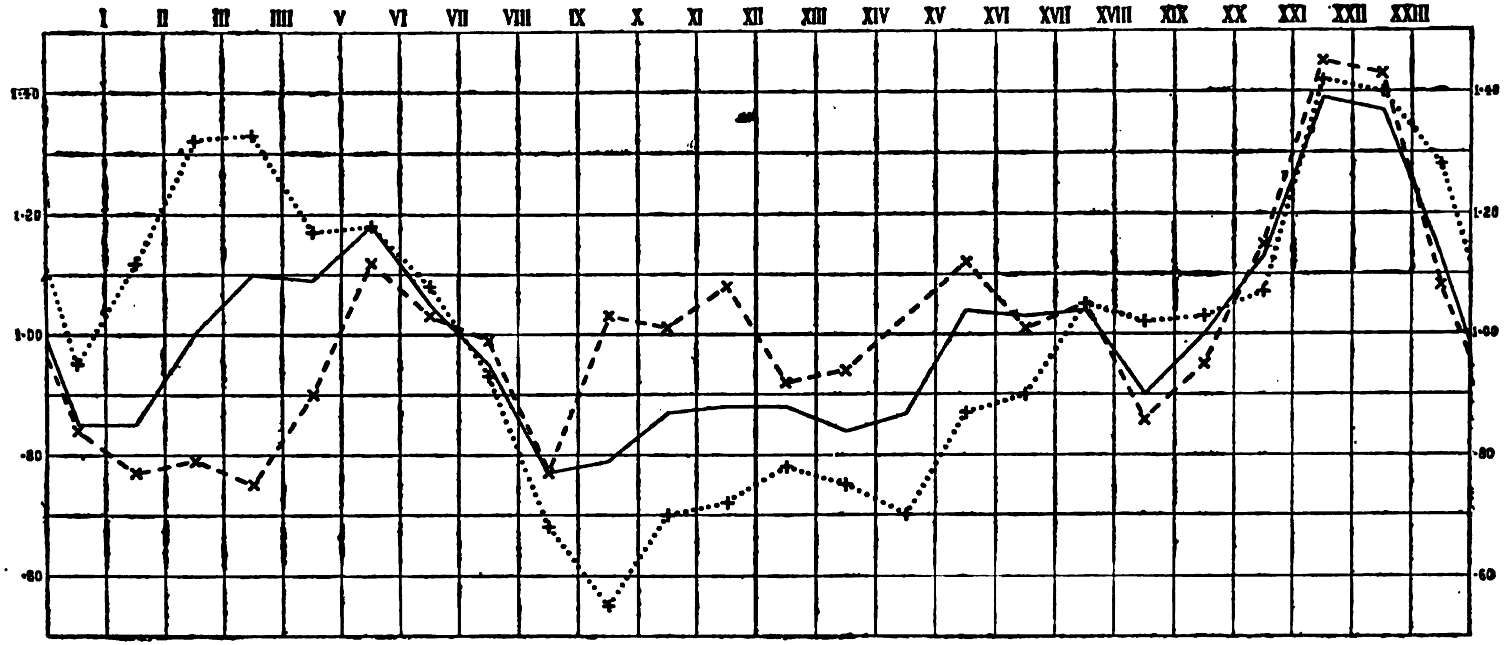

Fig. 1. Curves of diurnal distribution of earthquakes. The continuous line is the general curve obtained from all shocks. The broken line represents the distribution of shocks occurring when the sun's declination was more than 9°N. The dotted line is the curve for shocks occurring when the declination was more than 9°S.

Here we again see that the day shocks are proportionately more numerous when the sun has declination of more than 9°N. than when the sun is more than 9°S. of the equator, and that in the latter case the night shocks are proportionately more numerous than in the former. It is also evident, from the irregularity of distribution from hour to hour, that the number of shocks is not enough to give a near approach to the true curve, when plotted directly, and a process of smoothing has to be adopted. This has been done by adding together the number of shocks recorded during each group of three successive hours and, by regarding them as grouped round the centre of the middle hour, obtaining a fresh series of hourly means, from which a great deal of the irregularity of the curve has disappeared. The result is represented graphically in Fig. 1, so far as the shocks which occurred when the sun was more than 9° north and south of the equator respectively.

From this curve it will be seen that as regards the shocks occurring about two hours before midnight there is little difference, but that for the rest of the twenty-four hours the curve for south declination is steadily above that for north declination throughout the twelve hours of the night, and below it for the day. Moreover there is a distinct maximum in the earthquakes recorded round three hours after and two hours before midnight, while the earthquakes recorded near midnight are much more frequent than when the sun was more than 9° north of the equator. Turning to the shocks recorded when the sun was north of the equator, not only are they proportionately more numerous, than when it was south but there is again a distinct pair of maxima, shortly before and three hours after midday. Among the shocks recorded when the sun was within 9° of the equator we have maxima distinctly marked at about 5 hours after midnight and midday, another at about 2 hours before midnight and a less marked one at about 2 hours before midday.

There is consequently an approach to what might be expected if the tide-producing forces caused by the attraction of the sun had their effect in determining the time of origin of earthquakes, but it is also evident that, if these forces have any effect, it is so small and so complicated by other causes, giving rise to a greater variation in frequency than they do, that it is necessary to adopt some method of discussion, which will more or less completely eliminate the effects of variation, other than those due to the tide-producing forces.

The most obvious of these would be the conversion of the solar into lunar times. The moon moves through the heavens at a rate which brings it on the average about 50 minutes in advance of the sun for each day. If, then, we consider the interval between the two

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successive similar meridian passages of the moon as representing 24 lunar hours, and convert the recorded times into lunar times, it is obvious that, in a long series of observations, any irregularity of frequency, at any particular hour of solar time, will get spread over the whole of the lunar day, and in its place will be introduced any fresh irregularity due to the position of the moon. Now as the moon has twice the efficiency of the sun, as a tide producer, any irregularities due to the tide producing forces should be double as great as in the case of the sun.

Unfortunately the test cannot be applied in this case as, on trial, it was found that the series of observations was not sufficiently long to eliminate the effect of the diurnal irregularities.

This method of elimination failing, we must fall back on the recorded times, to see whether there is no other method of eliminating the non-tidal diurnal variation, and a method appears which depends on the fact that, taking the year as a whole, the tidal effect is on the average the same all through, since the times of passage of the tidal circles during the six hours on either side of midnight are the same for a south declination as the times on either side of midday in the case of the same amount of north declination.

If, then, we take the recorded frequency of shocks for each hour, write them down in two lines, placing those for the hour after midday under those for the hour after midnight and so on, and then add the two lines, we obtain a series of numbers representing the semi-diurnal curve of frequency. In this curve any diurnal periodicity, which is of a harmonic nature, is completely eliminated, and any non-harmonic periodicity largely reduced in amount. On the other hand any semi-diurnal periodicity which is harmonic in character, or which, if not harmonic, has its irregularities similarly distributed with regard to midnight and midday, will be exaggerated; that is to say the effect we are looking for will be increased, while that which we wish to eliminate will be reduced, in amount.

In the next tabular statement the process is illustrated as regards the total number of shocks, and four more lines given, showing the results obtained in the case of certain combinations of shocks, which will be referred to further on.

V.—*Semidiurnal distribution of Shocks.*

Hours.	0 12	1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23
All shocks 0 h. to 11 h.	33	44	59	55	61	57	70	40	41	42	43	54
Do. 12 h. to 23 h.	43	43	48	47	71	46	48	50	60	71	90	58
Sum	76	87	107	102	132	103	118	90	101	113	133	112
Sum ÷ Mean	·72	·81	1·01	·96	1·26	·97	1·11	·85	·95	1·06	1·25	1·05
Day shocks > 9° N. Night shocks > 9° S.	·80	·82	1·23	·99	1·18	·84	1·11	·67	1·01	·87	1·52	96·
All shocks 9° N. to 9° S.	·53	·87	·77	1·20	1·61	·84	·94	·97	·94	1·08	1·14	1·11
Day shocks > 9° N. All shocks 9° N. 9° S. Night shocks > 9° S.	·69	·84	1·04	1·08	1·36	·84	1·04	·80	·98	·95	1·36	1·02
Night shocks > 9° N. Day shocks > 9° S.	·77	·77	·94	·71	1·00	1·23	1·26	·94	·94	1·29	1·03	1·12

Here we see two very marked maxima, in the distribution of the shocks, one during the fifth hour after, the other during the second hour before, the meridian passage, and these maxima may be taken as grouped around 4½ hours and 10½ hours of the morning and afternoon. That is to say they both follow by 1½ hours the epoch corresponding to three hours before and after the meridian passage, a time which corresponds more closely to the passage of the maximum rate of change of tidal force, than to that of the circle of maximum horizontal stress.

If we turn to the next line in the table, representing the distribution when the tide producing forces may be expected to be most effective, we find the same features, except that the maximum following the meridian passage is less marked than that which precedes it, and that though the latter is proportionately greater than in the case of the whole number of shocks the former is less.

The next line shows the distribution when the sun is within 9° of the Equator, when on the average the conditions—so far as the tide generating forces are concerned—are the same during the day as the night. Here we find the two maxima again, but it is that following the meridian passage which is most conspicuous, the other being small and ill defined.

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The fact is that in both these cases the total number of shocks considered is too small to get an approach to a true average, and, in this small number of shocks, accidental variations of distribution may produce an irregularity of the curve which exceeds its normal variation.

To some extent this difficulty may be overcome. If we refer to the tables I and II, we will see that when the sun is within 9° of the equator, there is not a very great variation in the times of passage of the tidal circles as compared with the times of passage during the day when the sun is north, and during the night when it is south, of the equator. On the other hand the night when the sun is north, and the day when the sun is south, of the equator, show a much greater range of time in the passage of the circles and not only is the range of time greater and the effect consequently less conspicuous, but during part of the time the maximum of horizontal force is not felt at all, and during the rest of the time the passage is so oblique that the rate of change is slow and the tidal forces probably less effective.

Excluding these shocks we may add together the two groups of shocks already considered and so obtain a larger one, in which the tidal effect is tolerably uniform. The result is given in the table, and shown graphically in Fig. 2. Here it will be seen that the two maxima preceding and following the meridian passage are both distinct, and exceed those obtained from the total number of shocks.

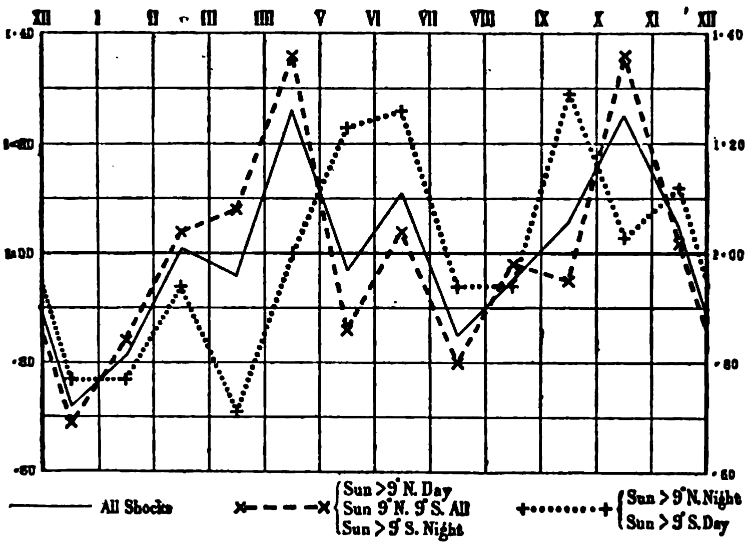

Shillong Seismograph 1897-1901. Semidiurnal curve of frequency.

Fig. 2. Semidiurnal curves of frequency.

We have consequently the effect which was to be looked for if the frequency of earthquakes is influenced, either by the amount of the horizontal tide generating force, or by the rate of change of the tide generating forces, and the fact that this effect becomes more marked the larger the number of shocks—suitably distributed as regards time of occurrence—which are taken into consideration, lends support to the supposition that the apparent relation between cause and effect is a real one.

Passing on to the last line, representing the night shocks when the declination is north and the day shocks when it is south, that is to say a time when the rate of variation of the tidal stresses is at its lowest and less effect to be looked for, we find that the marked maxima have disappeared, and that there is an almost equally distinct increase in frequency about six o'clock, that is at a time corresponding to the passage of the circles of maximum vertical force. This has the appearance of indicating that the purely vertical stresses have less influence than those which have a large element of horizontal stress, and that the effect of the former only becomes apparent when that of the latter becomes small. Too much stress must not, however, be attached to this conjecture, as the number of shocks dealt with is smaller than in any of the other combinations, and the possibility of fortuitous irregularities in the curve more probable in a corresponding degree, and besides this the effect here only lags half an hour behind the presumed cause, while in the case of the 4½ and 10½ hour maxima it lags 1½ hours behind the presumed cause.

It appears then that the tidal stresses have a distinct effect in determining the time of origin of earthquakes, though their influence is small in proportion to other causes, but at the same time it is necessary to enter a caution that, though the facts in this case seem to support the conclusion, they are far from proving it. For proof a more extended series of observations are required, not only from Assam, but from other stations also, and even in the record discussed in this paper there is reason to doubt the correctness of the conclusion, inasmuch as the effect found appears to be out of proportion to the cause invoked.

When we consider that the maximum upward tidal force exerted by the moon is only 1/8, 450,000 of gravity, that this corresponds very closely to the difference in downward strain which would be produced by the removal or replacement of half a grain on a one-ton weight, that the maximum horizontal tide generating force is only three quarters of this, and finally that the tide generating forces set up by the sun are a little less than half of those set up by the moon, it is surprising that they should have any effect at all. On the other hand when we consider that these

V
(XII.9)

forces are sufficient to give rise to the tides, and that the difference between the spring tides and the neaps is due to the forces whose effect has been searched for in this paper, it is quite conceivable that they should not be without effect in determining the moment at which a gradually increasing strain becomes too great for the resistance, and the fracture is produced which gives rise to an earthquake.

IV.—CONCLUSIONS.

From what has gone before we may draw the following conclusions.

1. That there was a very large variation in the diurnal distribution of earthquakes in Assam during the years 1897-1901, shocks being most frequent between 10 and 11 P.M., and again between 6 and 7 A.M. This greater frequency is a real one and not merely due to a larger number of shocks happening to be recorded at those times.

No satisfactory cause can be assigned for this irregularity of distribution, which must for the present be accepted as a fact true for a limited period and area.

2. Superimposed on this large and unexplained variation in frequency, there is a smaller variation which has the appearance of being due to the tidal stresses set up by the attraction of the sun.

3. If this smaller variation is really due to tidal stress, then the horizontal stress is much more efficient than the vertical stress, and the effect is less due to the amount of the stress than to the rate and range of its variation.

4. That these conclusions must be taken as purely provisional and require verification from a more extended series of observations. For their verification we require an instrumental record from some station within or near the tropics, where earthquakes are fairly frequent, and extending over 19 or 20 years.

N° V
(XII.2)

No. V
(XII.V)

EARTHQUAKE OF 12TH JUNE.

On the afternoon of the 12th June, at five o'clock in the afternoon, Calcutta was startled by a shock of earthquake such as it had never felt before; many houses were more or less injured, the steeples of two churches broken off, and hundreds of people rendered homeless. Soon, however, it became evident that other places had suffered far more severely than Calcutta. Railway and telegraphic communication was cut off and it was only as the days wore on and news tardily arrived from the north and from the east that we found ourselves faced with a cataclysm which rivaled the classic earthquake of Lisbon in violence and extent.

No sooner were we aware of the scale of the event we had to deal with than preparations were made for its thorough investigation. The immediate succession of the rainy season on the earthquake rendered it imperative that observation of its effects should be made with all possible promptitude, and every officer of the Geological Survey then in Calcutta was despatched to observe and investigate. At the same time orders had been issued by Government to the local authorities to report fully on the effects of the earthquake. All the telegraph offices throughout India were instructed to report the time at which it was felt, and similar information was called for from all the station masters on the lines of Railway within the area likely to be affected. Circulars have also been widely distributed and communicated to the press, which has readily assisted in the endeavour to collect information.

The replies to these circulars and the reports called for from Government officials are now pouring in at a rate which defies satisfactory analysis, but some of the main facts about the earthquake, which have been already established, may be noticed here.

The area over which the earthquake was felt is enormous. On the east it has been reported as felt from the furthest extreme of Assam, at Mogok, Magwe, and Akyab in Burma; on the south, at Masulipatam in Madras, and Ellichpur in Berar; from Surat, Ahmedabad, Mount Abu, Ajmere, Panipat and Simla on the west. On the north it was felt at Katmandu; at Gnatong on the frontier of Sikkim and Thibet, it was severe enough to overthrow some of the barrack chimneys, and it is reported to have been felt at Lhassa. Besides these observations which are free from doubt, the shock appears to have been just perceptible to a few people, particularly sensitive or specially favourably situated in Dharmsala, Madras and Pegu. Omitting these last, there remains the fact that the range of the shock was over 24 degrees of longitude and 16 degrees of latitude or an area of over 1,500 miles in length and 1,000 in width, or, say, 1,275,000 square miles in all.

The area over which the shock was destructive is also great; from Darjiling, Monghyr and Calcutta on the west, to Jorhat on the east, damage and occasional destruction was caused to buildings, but this destructive force reached its maximum in Shillong, Cherrapunji and Tura. In Shillong, it may be said almost without exaggeration, that not one stone has been left standing on another. All masonry buildings have been levelled to the ground, and this, not by overthrow, but by a shattering of the walls into fragments, on the top of which the roof subsided. The nature of the destruction will be best understood by a reference to Plate XVI, which gives a view of Government house after the earthquake, drawn from a

VII-4-10

temperatures. This is the substance evidently referred to by Dr. J. E. T. Aitchison in his "Notes on the Products of West Afghanistan and of North-East Persia" (*Trans. Ed. Bot. Soc.*, XVIII, reprint, p. 7), as limestone composed of layers of different colours together with alabaster and "chrysolite." In a note at the end of his paper Dr. Aitchison says the so-called "chrysolite" specimens were identified in Edinburgh as aragonite containing traces of strontia. I am indebted to Dr. Maynard for calling my attention to this note.

C.—SEDIMENTARY ROCKS.

The few specimens of sedimentary rocks collected by the Boundary Commission being without notes as to their stratigraphical relations deserve only a brief record of their characters. Shales, limestones, quartzites and conglomerates were brought from the neighbourhood of the Khwája Amrán. In the conglomerate the pebbles were slightly rounded and composed of quartz, quartzites and granitic rocks, the last sometimes showing most perfect micrographic structures. The quartzites and conglomerates are impregnated with infiltrated carbonate of lime. Coral limestones in rolled fragments were found at the foot of the Sarlat range, and on the east side of the gorge at Amír Cháh.

D.—ECONOMIC MINERALS.

Near Kartárkar, Kacha Koh, and Saindak which are evidently close to the site of a dying volcanic centre, specimens of excellent transparent selenite, native sulphur and galena were obtained. Sulphur and alumstone were also obtained in the Koh-i-Sultan near the site of an extinct or dying volcano. The soft ferruginous lithomarge, known as *mak* or *giri* and used for dyeing, occurs in the hills south of Saindak and in the Koh-i-Sultan.

The remains of extensive copper smelting works were discovered near Robat II (Lat. 29°49′; Long. 61°6′).

A large dried up salt marsh occurs near the northern end of Lora Hamun (Lat. 29°27′; Long 64°52′). The salt being in the vicinity of recently extinct volcanoes is probably of volcanic origin.

Limestone occurs at various places, and a yellow translucent calcite was found in the neighbourhood of the Koh-malik-do-khand.

Notes from the Geological Survey of India.

Dysluite from Madras.—A new mineral and a new locality for a rare mineral may be recorded. Dysluite, the zinc-iron-manganese variety of gahnite has been found in the corundum-bearing granite of Padiyur in Coimbatore, in veins with felspar, quartz and zircon.

Columbite from Hazaribagh.—A new locality for this mineral may be recorded, specimens from the Government forest of Koderma in Hazaribagh having been presented to the Museum by Mr. Gow Smith. The present specimens differ from those previously recorded from Nawadih (Rec. xxvii, p. 8) in having a considerably higher specific gravity, *viz.*, 6·19 as against 5·54.

photograph taken by Mr. F. H. Smith, of the Geological Survey. The other drawing on the same plate shows the influence of construction; the central portion of the hotel was built of stone and has been shaken to the ground. The two ends, however, which were additions to the original building and built of a wooden framework filled with reeds plastered with mud, have stood though severely shaken.

At Shillong it is possible to form some idea of the violence of the shock. In 1882 a seismometer composed of a series of cylinders of various diameters was set up. The largest of these is 12" by 9" diameter, and the whole series was overthrown to the north-eastwards. According to Omori's formula a cylinder of these dimensions would be overthrown in a direction away from the origin of the shock, as these were, by a velocity of wave particle of 2 feet per second and if we take the period of vibration as 1 second which is about that of the more severe shocks in Japan, this would imply a range of motion of 7·4 inches. In other words, the violence of the shock at Shillong, while it lasted, was at least equal to a backward and forward shake of 7 inches repeated 60 times a minute. If the range of movement was less, the rate of shaking must have been greater; if the movement was slower, the range of motion must have been greater in the same proportion.

That few structures, except those most strongly braced together or possessed of a very great flexibility, could stand this is not difficult to understand, and the violence of the to and fro movement will perhaps be best appreciated from the fact that the very boundary pillars have been shaken to pieces and heaps of broken road metal by the roadside were scattered out in layers of a few inches deep.

Earth-fissures and sand-craters are reported throughout the alluvial plains from Purneah on the west, to Jorhat on the east. They are, as is well known, only superficial and secondary results of the earthquake wave, but afford, among other information, instances of the extraordinary manner in which observation may be influenced by imagination. Numerous accounts speak of a strong sulphurous smell of smoke issuing from the vents and of hot, even boiling hot, water being poured forth. More temperate accounts show that the sulphurous smell was that of decaying vegetable matter, that the smoke was dust, and that the heat of the water was no greater than was to be expected in the middle of June. Closely allied in origin to the sand vents was the filling up of all the drainage channels, tanks and wells over large areas. That this was not due merely to an outpouring of sand, but to an actual forcing up of the bottoms of the hollows is shown by the effect on bridges, whose piers have been forced bodily upwards, as is shown in Plate XVII, reproduced from one of the admirable series of photographs taken by Messrs. Kapp & Co. of Calcutta. The other figure on the same plate, reproduced from one of the same series of photographs, shows how the rails have been affected by the movement of the surface alluvium consequent on the shock.

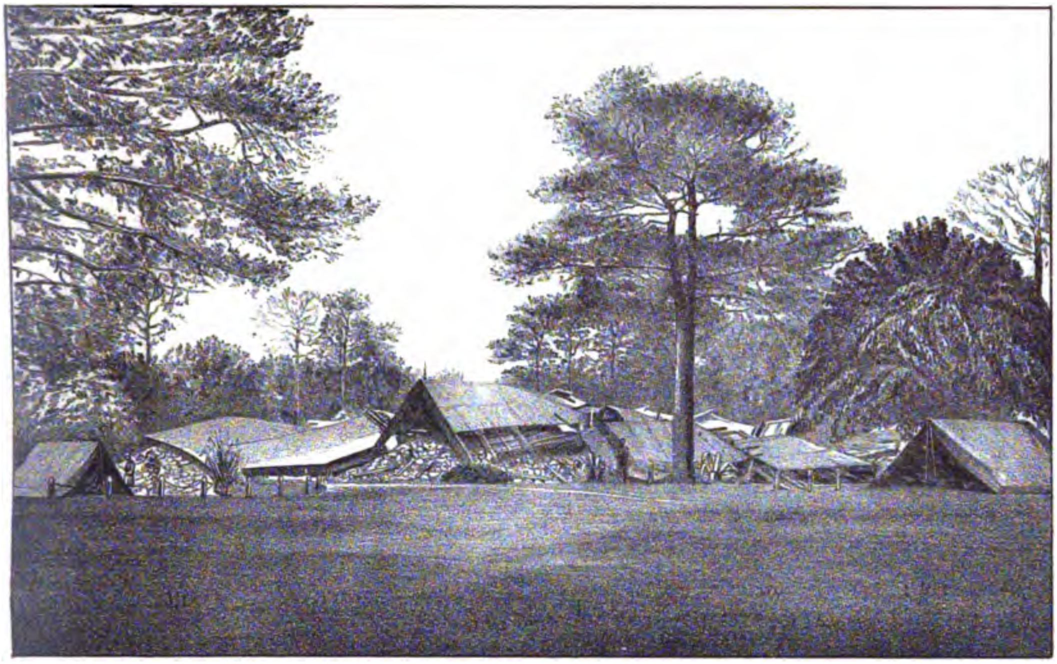
The rate of transmission of the wave was very high, in fact it has been stated in newspapers, and frequently spoken of, as having been felt simultaneously throughout Northern and Eastern India. Such was not the case, however, though the time the wave took to travel from its origin to the furthest point at which it was sensible to unaided observation does not appear to have been more than 8 minutes. The very large number of time observations, of every degree of accuracy, which have been communicated, have not yet been discussed, and no definite statement can be made, but a few selected at random as apparently good give an average rate of transmission of about 10,000 feet per second or over 112 miles per minute. This result indicates the order of magnitude of the figures we have to deal with, though it cannot be accepted as final, or more than very approximate. The prevalent idea of the simultaneousness of the shock is disproved by a quaint report by the telegraph master of Chupra, who relates that he was working Durbhunga when there was suddenly a stoppage due to the earthquake at Durbhunga, and the signaller leaving the instrument there, and immediately afterwards the earthquake was felt by him. According to the daily papers a similar incident took place at Dhubri, which was at the time in communication with Goalpara.

Beyond the area over which the earthquake was felt its effects were traced instrumentally at Bombay, where the instruments in the magnetic observatory were affected by a disturbance commencing between four and five minutes past four, local time, or 16 h. 34 m. Madras time, that is, 6 minutes later than the shock was felt at Calcutta, and about 9 minutes after the probable time at which the shock started on its way from the place of origin, somewhere below the Garo or Khasia hills.

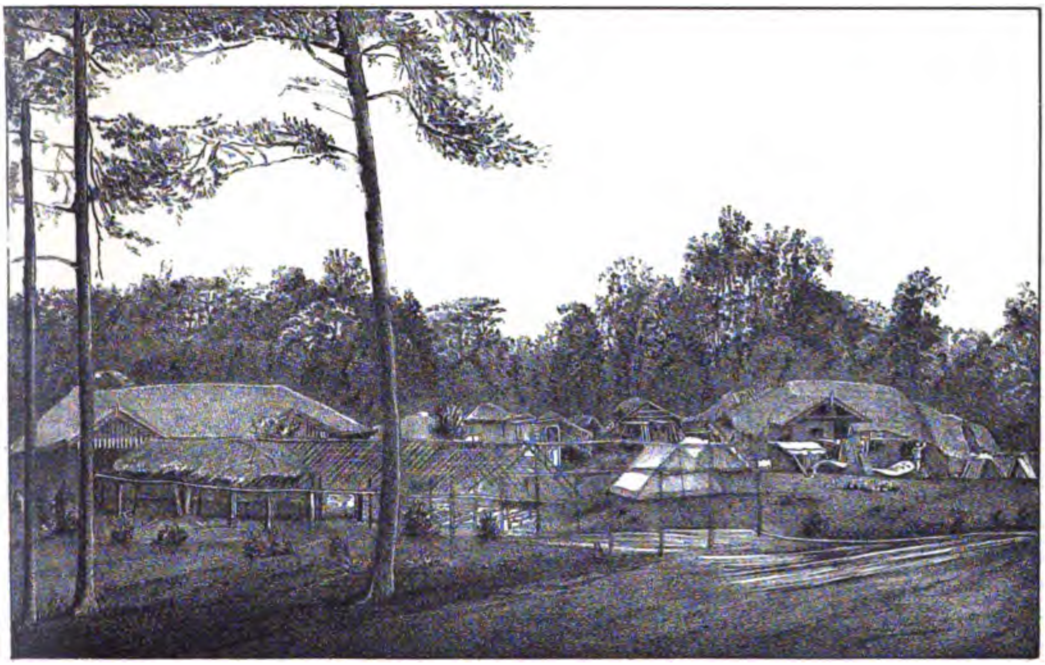
The effects of the shock are said to have been traced at Grenoble; and at Edinburgh a letter from Mr. Heath, Assistant Astronomer, to *Nature*, gives the time at which the tremors were first felt as June 11th, 23 h. 18 m. G. M. T.; they lasted about 10 minutes and then ceased, and violent oscillation again set in at 0 h. 32 m. G. M. T. of 13th June and continued up to 1 h. 12 m. They were equivalent to a tilting of the ground through 20 seconds of arc. Greenwich mean time June 11th, 23 h. 18 m. (astronomical) corresponds to Madras time 16 h. 39 m. of 12th June, (civil); 0 h. 32 m. G. M. T. of 13th June corresponds to Madras time 17 h. 53 m. of 12th June. If both these sets of tremors were due to the same earthquake the first must have travelled the distance from the origin to Edinburgh, starting at about 16 h. 25 m. Madras time, in 14 minutes, the other in 1 h. 28 m.

These few notes form no adequate account of the earthquake; this is in preparation, but the collection and discussion of the information will take some time. Meanwhile what has been written will serve to show the order of magnitude of the cataclysm of 12th June 1897, an earthquake unsurpassed by any since the great Lisbon earthquake of 1st November 1755, and rivalling this in magnitude of the area over which it was felt, surpassing it indeed if we exclude the doubtful records of the earlier shock.

31st July 1897. R. D. OLDHAM.



GOVERNMENT HOUSE SHILLONG.

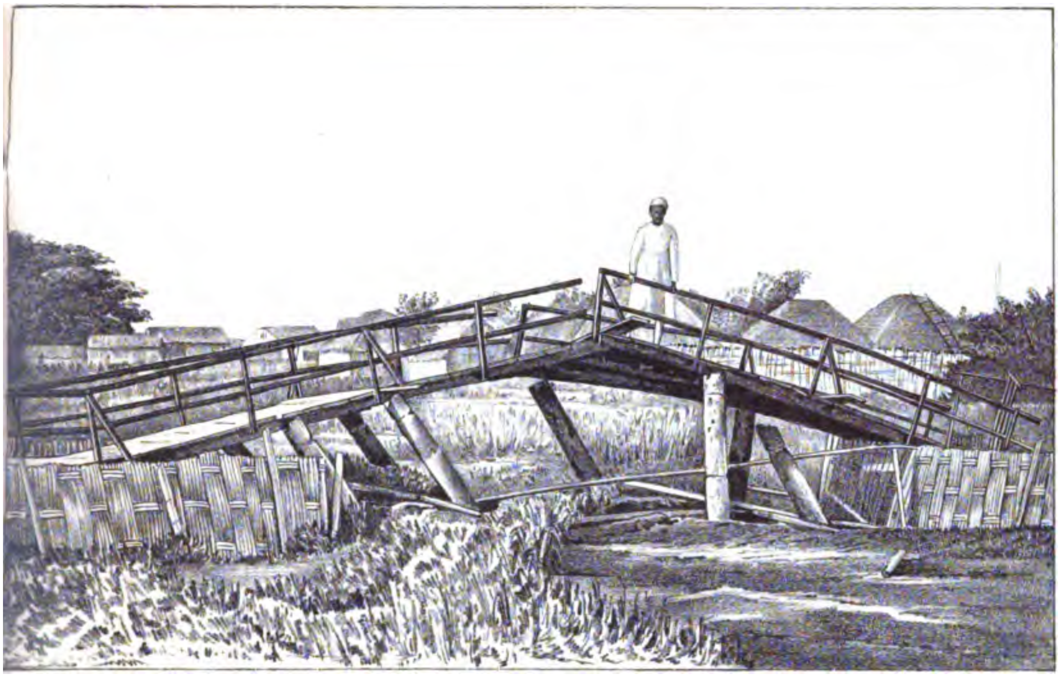


FERNDALE HOTEL SHILLONG.

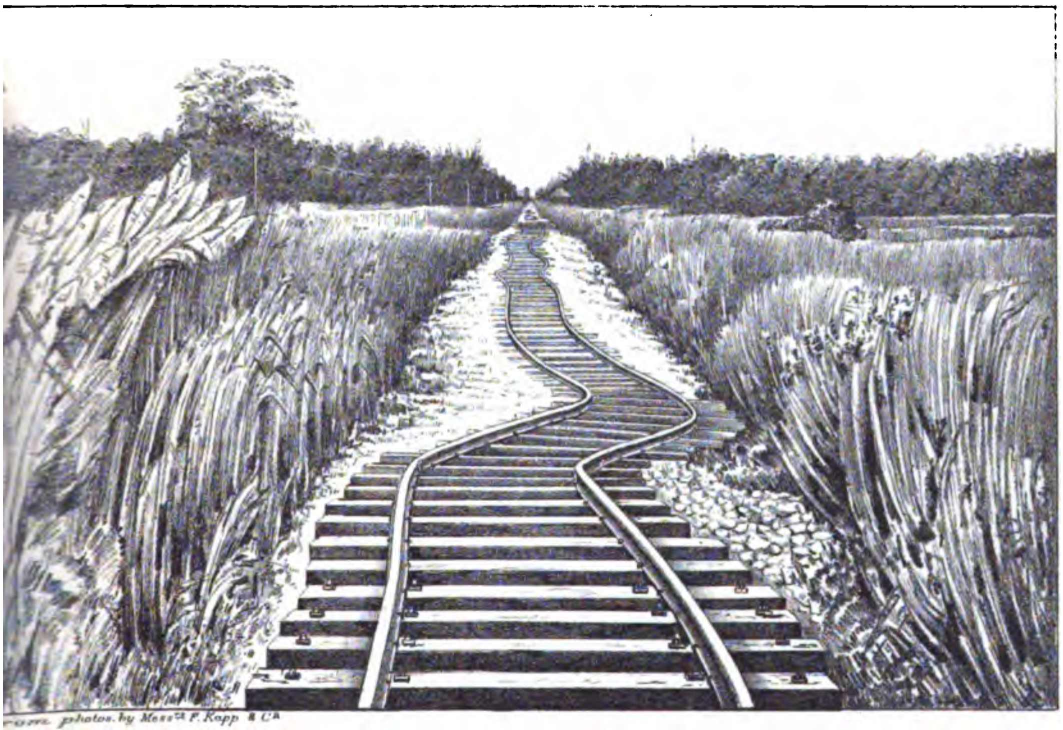
GEOLOGICAL SURVEY OF INDIA.

Earthquake of 12th June 1897.

Records, Vol: XXX. Pl. XVII.



BRIDGE ACROSS NALLAH AT HALDIBARI.



rom photos. by Messrs F. Kapp & Co.

LINE BETWEEN HALDIBARI AND MOGHAL HAT.

No. V
(XI. 2)

NOTE
ON
THE EARTHQUAKE
OF
31st December 1881,

BY

R. D. OLDHAM, A.R.S.M.,

GEOLOGICAL SURVEY OF INDIA.

[With a Map.]

G. I. C. P. O.—No. 37 S. G. S.—6-5-84.—30.

[From the Records, Geological Survey of India, Vol. XVII, Pt. 2, 1884.]

Note on the Earthquake *of 31st December 1881, by* R. D. Oldham, A.R.S.M., *Geological Survey of India.* (With a map.)

On the morning of the 31st December 1881 a severe earthquake was felt over a large portion of the Indian peninsula and Bengal, affecting also the Burmese coast and causing much damage in the Andaman and Nicobar islands. A considerable amount of material, comprising newspaper extracts, official reports and private letters, having been placed at my disposal, I propose giving a brief notice of the more important features of the shock.

In Bengal it was felt as far as Chunar (?), Gaya, and Hazaribagh; Akra, in the 24-Parganas, was shaken; and at Akyab it was followed by the eruption of a mud volcano in Ramri.[1] There is no record of its having been felt at Rangoon or Moulmein; at Tenasserim it is doubtful, though it was felt in the Mergui archipelago; to the south it is reported as having been 'severe' at Acheen in Sumatra, and in N. Lat. 3° 54′, E. Long. 91° 21′ it was felt by the ship *Mount Stuart;* at Ootacamund it is recorded, as also at Calicut: thus the area over which it was felt measures about 1,600 miles from north to south and 1,500 miles from east to west, or 2,000,000 square miles in all.

Such briefly is the summary of the information contained in the daily papers, and as no observation of scientific value is recorded in them which has not been placed at my disposal in another form, I shall refrain from repeating the vague, when not misleading, statements of the time and nature of the shock which were so given to the world.[2]

There is, however, one published notice which contains much valuable information. I refer to the note by General Walker, and Major M. W. Rogers, R.E. (originally published in the Annual Report of the Trigonometrical Survey, and reprinted in the Proceedings of the Asiatic Society of Bengal, March 1883, page 60) on the records left by the earthquake, and its consequent sea-wave on the tidal gauges fixed along the shores of the Bay of Bengal, illustrated by reductions from the original records and a chart of the Bay of Bengal, on which Major Rogers has marked what he considered to be the focus of the disturbance. For the benefit of those who may not have access to the original, I subjoin a short abstract of the information contained.

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[1] Records, G. S. I., Vol. XV, p. 141.

[2] I may, however, mention one letter by Mr. W. G. Simmons of Calcutta published in the *Indian Daily News.* He seems to have been at some trouble to collect information, and I have to thank him for liberally placing it at my disposal.

At Port Blair, the forced sea-wave, indicating the arrival of the earth-wave, is indicated at *7h.* 44′;[1] the first sea-wave arrived at *8h.* 3′, followed by others at 15 minutes interval, with a height of 3 feet from crest to hollow, the disturbance not subsiding entirely till 21*h*.

Diamond Harbour.—Sea-wave hardly perceptible; arrived at 15*h*. 10.′

Dablat.—First sea-wave at 13*h*.; disturbance continued till 21*h*.

False Point.—Forced sea-wave at 7*h*. 54′. Sea-waves small; the first arrived at 11*h*. 15.′

Vizagapatam.—The sea-wave arrived at 10*h*. 43′, followed by others until midnight.

Madras.—Sea-wave arrived at 10*h*. 18.′

Negapatam.—The first wave, which arrived at 10*h*. 15′, measured 4 feet from crest to hollow, and was followed by others until midnight.

Paumben.—First wave at 11*h*. 32′; disturbance lasted till midnight.

At Calcutta the time of arrival of the earthquake was noted by Mr. James Murray, who writes, in reply to my enquiries, that he was reading in an upstairs room when feeling the shock he immediately ran downstairs and marked on the glass of his standard regulating clock the exact position of the second's hand and then waited to note the time of cessation of the motion; afterwards he carefully took with a second's watch the time that it occupied to do all he had done between the moment when he first felt the shock and when he made the mark on the glass of his clock, adding this and the error of the clock on that morning, he obtained the times of commencement and cessation as 7*h*. 37′ 45″ and 7*h*. 42′ 0″, Calcutta mean time, or 7*h*. 55′ 2″ and 7*h*. 59′ 17″ Port Blair mean time, respectively. This, I may add, is the only observation of real value made at the time and not automatically recorded that I know of in connection with this shock.

At Madras a clock in the office of the Master Attendant, electrically controlled from the astronomical observatory, was stopped at 7*h*. 5′ 45″ local time, or 7*h*. 55′ 36″ Port Blair mean time.

Port Blair is the only place where any damage was done to masonry buildings, and it is to be regretted that the damage should be so little instructive as is the case. The infantry barrack, of which I have drawings showing the damage done, is a long, narrow building situated on the crest of a hill, the major axis bearing N. 20° E., while the cross-walls bear E. 20° S. The latter were severely cracked, while with a single exception not a crack has opened in the longitudinal walls; this might indicate a direction nearly N. 20° E. or S. 20° W., but is most probably, as will be seen from the sequel, due to their being of less solid construction. As regards the angle of emergence the cracks do not indicate much, merely pointing to a nearly horizontal or nearly vertical emergence; the former would be indicated by the fact that a chimney shaft 60 feet high was cracked but not overthrown as it certainly must have been by a severe shock with a moderate angle of emergence, but as this supposition is irreconcileable with the position of the seismic vertical obtained from more trustworthy observations we must suppose the angle of emergence to have been nearly horizontal and the violence of the shock to have been considerably exaggerated.

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[1] These times differ from those originally given, having been retaken with greater care from the original records. The times here and throughout this notice are reduced to Port Blair mean time, and for the sea-wave are the time of arrival of the crest of the first wave.

In the Car Nicobar extensive damage was done to the cocoanut groves and huts of the natives, and vents similar to those described in connection with the Cachar earthquake of 1869[1] were opened in the sandy soil. It was noted by Major W. B. Birch, to whose report I am indebted for the facts, that on the margin of the seashore the trees were left standing, while further inland they were overthrown. This may have been due to the fact that the edge of the land was protected from the earthquake by the slope of the seaward face being steeper than that of the emergence of the wave but I am inclined to believe that Major Birch's suggestion, that the soil near the sea margin is firmer than that further inland, is more likely to be the true explanation. The sea-wave broke on this island and it is recorded that the water penetrated into the houses of the Burmese residents which stood on platforms of less than 2½ feet high, while those on higher platforms escaped.

I will now proceed to the discussion of the data available, which are, *firstly*, the records of the arrival of the earth-wave at Calcutta, Madras, False Point, Port Blair, and Kisseraing; and, *secondly*, the records of the arrival of the sea-wave at the stations mentioned above; the latter, however, are owing to irregularities in the depth of the Bay of Bengal of no use in determining the position of the seismic vertical. Of the first category, the records from Madras and Calcutta are undoubtedly good, those from Port Blair and False Point are good as far as they go, but only pretend to give the time to the nearest minute, while the fifth is, as will be subsequently shown, unfortunately open to an element of doubt.

It has been pointed out by Professor Milne that if the earth-wave arrives at two points on the earth's surface at the same moment of absolute time and a straight line be drawn joining those two points, the seismic vertical should lie somewhere on the line bisecting it at right angles, supposing, that is to say, that the surface of the earth were a plane and its substance homogeneous; on the same suppositions if the time of arrival is known at three stations and circles be drawn round the two at which the arrival was latest with radii equal to the distance traversed by the wave in the respective absolute differences of time between its arrival at those stations and at the first station, and a circle be drawn passing through the first station and touching the circles drawn round the second and third stations, the centre of that circle will represent the position of the seismic vertical. Neither of the assumptions are, of course, theoretically correct, but these constructions give a rapid and convenient method of finding the approximate position of the seismic vertical. I have, for the purposes of the first construction, taken the time of arrival at Calcutta and Madras as identical and represented it on the map by fine firm lines; the second construction is not represented, but the centres obtained are indicated by dots with the letters C. M. B. for the centre deduced from the Calcutta, Madras, and Port Blair observations, and F. M. B. for that due to those at False Point, Madras, and Port Blair. It will be seen that the first-named lies within 30 miles of the true position of the seismic vertical, the error being due almost entirely to the unavoidable distortion of the map; the other shows a greater error, due partly to a less average accuracy of the observations and partly to the fact that the stations are less favourably situated for applying the construction. Taking Calcutta, False Point, and Port Blair, we get an impossible centre at the mouth of the Irrawadi, the fact being that this construction is only practically applicable when the three stations form a pretty open triangle. The Madras, False Point, and Kisseraing observations give the centre where Major Rogers placed it, but this result is vitiated both by the small inaccuracy of the False Point observation and the greater one at Kisseraing, which will be referred to hereafter.

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[1] Memoirs, G. S. I., Vol. XIX, part I.

Starting with the C. M. B. centre, a brief investigation proves it to be about 30 miles too far south; so taking Lat. 15° Long. 89° as the centre provisionally, we find that the geodetic distance from this point to

	Feet.
Port Blair is	1,804,475
Calcutta is	3,117,585
False Point is	2,888,620
Madras is	3,177,850
Kisseraing is	3,563,660

Subtracting the distance to Port Blair and dividing the results by the respective differences of time, we get a velocity of transit as between Port Blair and

	Feet per second.
Calcutta of	1,957
Madras of	1,948
False Point of	1,807
Kisseraing of	2,666

and as between Calcutta and Madras of 1,746 feet per second—a not impossible result, as the difference of distance would lie mainly in alluvial deposits, though possibly indicates that the centre is about half a mile east of the position assumed.

The low velocity as between Port Blair and False Point is easily explicable by the fact that the observations are only given to the nearest minute; had the time interval been 9 minutes instead of 10 minutes, it would give a velocity of 2,001 feet per second, while an interval of 9¾ minutes would bring it almost into accord with the Calcutta and Madras observations. From this we may conclude that the time recorded at Port Blair is too early, or that at False Point too late, or possibly both. It must be borne in mind that the times were taken from the trace left by a pencil on a sheet of paper and on a scale on which it would be difficult to distinguish between, say, *7h.* 53′ 15″ and *7h.* 53′ 45″, though one should be recorded to the nearest minute as *7h.* 53′ and the other as *7h.* 54′.

The Kisseraing observation, however, gives a velocity which is inexplicable on this supposition, and I cannot but consider the error due to an actual error of observation, as, though it can be approximately reconciled with those from the western stations, this can only be done by taking the latter out of accord with each other and giving an inadmissibly high velocity to the whole series. The only published record of this observation is that in Major Roger's note, where he says that "at Madras, False Point, and Kisseraing the shock was felt at about the same minute—*7h.*·55′ A.M.;" it will be seen that this is rather vague, and a personal application to Major Rogers elicited the fact that the original record had been destroyed, and it was consequently no longer possible to estimate the degree of accuracy of the time record. I fear we must reject this observation as of insufficient accuracy for the purposes of the investigation.

The position assumed above proves to be that which best reconciles itself to the excellent observations at Calcutta and Madras, and to the automatic records at Port Blair and in a less degree False Point; I shall consequently consider that the shock did originate vertically below a point situated in Lat. 15° N., and Long. 89° E., and that it travelled with a velocity of 1,950 feet per second, being that indicated by the Madras and Calcutta and Port Blair observations. Under these circumstances the time taken by the earth-wave to travel from the seismic vertical to

Port Blair would be	15′ 25″
Calcutta „	26′ 39″
Madras „	27′ 9″

(I omit Kisseraing and False Point owing to probable inaccuracies of the records.)

Subtracting these intervals from the recorded times, we have the Port Blair mean time of the origin of the earthquake deduced from the

Port Blair record as	*7h.* 28′ 35″
Calcutta „ „	*7h.* 28′ 23″
Madras „ „	*7h.* 28′ 27″
Mean	*7h.* 28′ 28″

But as the Port Blair record is liable to an unknown error being merely to the nearest minute, the mean of the Calcutta and Madras results, *viz.*, *7h.* 28′ 25″, is probably more accurate. Taking this result and reckoning back to the various stations we get the true time at

Port Blair,	*7h.* 43′ 50″	instead of	*7h.* 44′,	a probable error of . +10″
False Point,	*7h.* 53′ 6″	„	*7h.* 54′	„ „ . +54″
Kisseraing,	*7h.* 58′ 58″	„	*7h.* 55′	„ „ . —3′ 58″

The depth of the focus below the level of the sea cannot unfortunately be ascertained, the only records that could give the angle of emergence being from Port Blair and, as mentioned above, they are indefinite, and all we can say is that the emergence was nearly horizontal; from this we would deduce a focus situated at a small depth, probably about 5 or 10 miles, and being improbably over 15 miles from the surface.

In the shape of the area over which the shock was felt there is a notable peculiarity as regards its eastern boundary between Akyab and Tenasserim, which seems to be real and not merely due to insufficient information, for Rangoon and Moulmein are large cities with a considerable resident European population, so that the shock if felt could hardly have escaped record.[1] In the Mergui archipelago it is recorded as slight, and it is very doubtful whether it was felt at Tenasserim. To the south, west, and north the configuration is very different; the shock is recorded as severe at Acheen; it was felt by the ship *Mount Stuart* in N. Lat. 3° 54′ E. Long. 91° 21′; to the west it was felt at Calicut; and to the north is said to have been felt at Chunar, though Gaya is possibly the extreme limit. This peculiarity may in part be due to a difference in the rocks traversed, but not being fully accounted for in that manner clearly indicates that the shock had its origin in a fissure underlying strongly to the west. If we accepted the Chunar record, it would almost be necessary to suppose the fissure curved and bending round from about S.-W. to S.-E, rejecting it we come to the conclusion that this earthquake had its origin in a straight, or nearly straight, fissure bearing about N.-W. and S.-E. and underlying to the S.-W., a far more probable configuration than the first, and one which is not absolutely incompatible with the Chunar record, if that is correct.

When we come to examine the records of the tide gauges the first point to be noticed is the absence of any record from the stations on the Burmese coast, while the wave is shown to have reached points on the western coast of the Bay situated at a greater distance from the centre. This, however, ceases to be remarkable when we examine the records from the stations on the delta of the Ganges. At Dablat the height of the wave is 12 inches, while at False Point it is but 2 inches, and merely perceptible at Diamond Harbour; if on the delta of the Ganges, exposed to the full force of the wave, the mere shoaling of the waters produced such an effect, it is not surprising that a similar shoaling at the mouth of the Irrawadi should have entirely destroyed the wave already enfeebled by the barrier stretching between Cape Negrais and the Andaman islands.

Between the centre and Port Blair the wave must have travelled by a circuitous route, and as it is impossible to say what allowance is to be made for this it becomes impracticable to correctly calculate the rate at which it travelled. In all probability the first wave recorded came round the south of the island, while the curve bears ample evidence that the subsequent long-continued and complicated disturbance was due to the interference of the two sets of waves—one travelling from the north, the other from the south.

Taking, for convenience of calculation, the time of origin of the wave as 7*h*. 28′ 30″, the error so introduced being comparatively insignificant, and in any case certainly not greater than that due to want of accuracy in the records, we find that the mean rate of transit of the wave between the centre and

		Feet per second.
Paumben	is	281
Negapatam	„	359
Madras	„	311
Vizagapatam	„	173
False Point	„	213
Dablat	„	104

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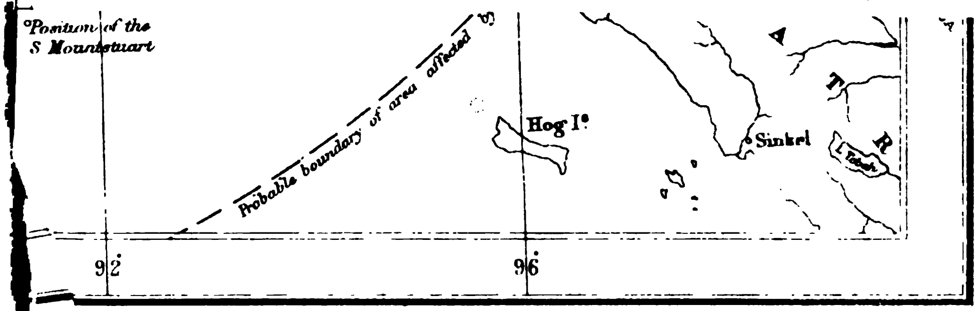
[1] As this note was passing through the press a paper on 'Earthquake disturbances of the Tides on the coasts of India,' by Lieutenant-General J. T. Walker, C.B., F.R.S., etc., appeared in 'Nature,' February 14th, in which it is incidentally mentioned that the earthquake was felt at Rangoon and Moulmein.



Position of the S Mountstuart
Probable boundary of area affected by
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Of these, the difference between the mean rates to Negapatam and Paumben is due to the long stretch of shallow water crossed in the latter case; but the difference between Madras and Negapatam is noticeable, and is probably due to the shallowing of the bay by the deposit in it of the silt brought down by the Kistna and Godavery rivers; this same cause has evidently affected the velocity between the centre and Vizagapatam, while the increase in velocity between the centre and False Point indicates that the wave has travelled over the depression between the two banks caused by the deposit from the Kistna and Godavery on the one hand and the Ganges and Brahmaputra on the other.

This notice, besides its direct bearing on the earthquake in question, shows the great value of a few really accurate time observations which, taken in conjunction with such simple observations as are within the power of all to make, have enabled me to fix the position of the seismic vertical, the velocity of transmission of the earth-wave, and the approximate form of the focus; had it originated inland there might not improbably have been sufficient information available to fix the depth of the focus—in the present state of our knowledge, one of the most important, if not the most important point to be determined with some degree of accuracy. Under these circumstances it is unfortunate that in the system of seismological observations recently sanctioned by Government an accurate determination of the time could not be incorporated, but with the unskilled even where not unsympathetic observers who are alone, as a rule, available, it would be impossible to secure that accuracy of record which alone would be of use; for this is especially a case where an inaccuracy, where accuracy is looked for, is worse than no record at all.

The following facts, though not strictly related to the earthquake under consideration, may with advantage be put on record here.

The master of the ship *Commonwealth* reported that he felt three shocks of earthquake on the 1st January 1882 in N. Lat. 8° 20′, E. Long. 92° 42′, and that the whole of the Car Nicobar was hidden by smoke. Major Birch on his subsequent visit to the island could find no foundation for this statement, so that in all probability it was only the smoke of a fire that was seen.

This shock was stated in the daily papers to have been felt at Khatmandu, in Nepal; but to judge from the more detailed information placed at my disposal, this cannot have been the same shock.

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